PHILCO CORPORATION (A)

Satellite Tracking and Commanding Console Layout

In August, 1964, Bill Williams, a Project Engineer in the Human Factors Section at Philco's Western Development Laboratories was considering how to test criteria used by designers in layout control console panels. Human factors design criteria, reports of human factors experiments, and statistical human factors data were available to designers in published literature and texts. One of the latest references used by designers in the Philco Human Factors Section was the Human Engineering Guide to Equipment Design, McGraw-Hill, 1963. This book was prepared by a joint Army-Navy-Air Force committee of the Department of Defense to help standardize criteria used in designing military equipment for human use. Bill said, "Little work has been done to date to evaluate the panel layout criteria available to designers. The Wright Air Development Division of the U.S. Air Force has recently requested proposals to establish even more detailed guides specifically for use in laying out console panels. I think an initial investigation should be made to determine whether or not such detailed criteria are needed."

Prepared in the Design Divsion of the Mechanical Engineering Department by J. Kendall Williams under the direction of Robert H. McKim, with financial assistance from the National Science Foundation. The assistance of Mr. William E. Williams is gratefully acknowledged.

Philco Corporation

Philco Corporation was founded in Philadelphia, Pennsylvania, in 1892. The company's first products were carbon arc lamps for Model "T" Fords and for street lights. By 1950, Philco's product line included television sets, radios, refrigerators, and military electronic communications equipment. In 1960, Philco Corporation had grown to include 12 operating divisions. The Corporation, whose gross sales then exceeded $400 million, was acquired as a wholly owned subsidiary of the Ford Motor Company in 1961.

WDL[1], the space systems center of Philco, was established in Palo Alto, California, in 1957. In 1964, WDL employed approximately 2100 people at the Palo Alto facility and 300 people at the NASA Manned Space Flight Center, Houston, Texas. Approximately 1000 of the total employment were engineers. WDL facilities included 135,000 square feet, 60% of which was devoted to scientific and engineering laboratories. WDL was divided into two major areas: Space Vehicle Operations concerned with communications equipment, navigation, and controls systems, and spacecraft power systems, and Space Support Operations concerned with ground station and antenna design, instrumentation for missile launch and recovery centers, and human factors design. A 1964 organization chart of WDL appears in Exhibit A-1.

Bill Williams worked in the Human Engineering Section of the Operations Design Department. This section was responsible under prime contract for human engineering design of ground support equipment and ground stations for a major ground control satellite station. The Air Force contract required specific attention to human factors design by specifying adherence to military specification MIL-H-27898A (USAF). Excerpts from this specification are described in greater detail in Exhibit A-2.

The Human Engineering Section employed approximately 14 "human factors engineers". Facilities of this section included a 20' x 20' test room for human factors experiments equipped with variable intensity overhead lights and refrigerated air conditioning. Adjacent to the test room was a test controllers' room equipped with a 16' long console in which test control equipment could be mounted. A one-way section of glass between the two rooms allowed the controller to observe test subjects during evaluation of console panels and equipment.

Bill Williams received a B.A. Degree in Psychology from Colgate University in 1959 and a M.A. in Industrial Psychology from Purdue in 1960. He served three years with the U.S.A.F. at the Rome Air Development Command, Rome, New York, conducting human factors research in the area of communications. He began his work for Philco in 1963. One of his responsibilities for Philco was to initiate and conduct research in WDL's Human Engineering Research Laboratory. Bill's first project was concerned with organizing a proposal for a series of communications studies for N.A.S.A. One study

[1] WDL - Abbreviation for Western Development Laboratories.

included in the proposal outline an investigation of the problem of distinguishing simultaneous conversations coming through a headset.

A typical project could begin with identification of a problem or area of interest which would yield new business or research contracts for Philco. Bill would then prepare a short plan or proposal detailing how he might approach the project, indicating financial and other benefits to the company. This plan would be submitted to his supervisor for consideration by WDL management. If approval to continue the project were given, it was generally in the form of an appropriation of man hours to be spent in preparation of a more detailed proposal. This proposal would be submitted to the appropriate U. S. government agencies or private organizations potentially interested in financially supporting the project. Such a proposal is called an "unsolicited proposal".

Projects also developed from "solicited proposals" requested by U.S. government agencies. Bill noted that many project leads came from readings in technical literature or from current projects at WDL. Projects also developed when design changes made by WDL engineers and designers outside the Human Engineering Section required additional human factors engineering. For instance, the Air Force recently requested a redesign of a satellite control station. The design changes included additional human factors effort in improving accoustical characteristics of the control room and revising traffic flow within the control room.

Request for Proposals

In August, 1964, W.A.D.D.[1] requested proposals from industry for the development of a handbook of criteria for A.G.E.[2] panel layout. It was necessary for interested parties to respond with a technical and cost proposal within one week. Bill worked with the other personnel in the Human Engineering Section in preparing a proposal to establish panel layout criteria for use by engineering designers in laying out panels. The first task which WDL would perform under this proposal was to list and describe all present satellite ground and support equipment employing control panels. This description would note the function of present panels and any constraints on their use. The next task was to evaluate the appropriateness of present design criteria for panels available in the literature and devise additional criteria if gaps in published criteria were found. Next, a testing program would be used to evaluate the effectiveness of the collected criteria for panel design.

After Philco's proposal was submitted, Bill Williams and others thought about the request and decided that there was a possibility that work should be done to evaluate the need for detailed panel criteria before formulating such criteria. Although Philco did not win the W.A.D.D. proposal, they did discuss their ideas on panel layout with W.A.D.D. personnel.

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[1] Abbreviation for Wright Air Development Division, Air Force Systems Command.

[2] Abbreviation for Aerospace Ground Equipment.

As a result of these discussions, it appeared that a Request for Proposals may be released in the near future for further investigation of panel layout.

Independent Development Project

In light of Air Force interest, Bill thought that future support for his idea might be available. He submitted to his supervisor a plan for an Independent Development Project outlining a study to determine the need for panel layout criteria. Approximately four or five requests for I.D.P.'s[1] originated in the Human Engineering Section each year. If approved, a typical I.D.P. was financially supported by W.D.L. Support for an I.D.P. terminated at the end of each calendar year. Bill noted that at the time he submitted his I.D.P. Request, he was involved in another project which was just phasing out. Several months of field evaluation of console equipment designed by W.D.L. for a satellite facility remained on this project. Bill was assigned to the I.D.P. project while devoting several hours a week to the field testing project. Another human factors engineer was assigned to perform the bulk of the field testing.

Although Bill hoped eventually to gain outside support for the panel criteria project, he noted that W.D.L. would gain directly from his study, if, for example, he established that working experience and exposure to human factors criteria were not essential to competent panel layout. Bill said, "We could have draftsmen do the layout part of panel design and relieve some of the load from our Human Factors designers."

Literature Search

Bill began a search of available literature concerned with panel layout. He commented, "While my search was not intended to be an extensive one, I surveyed enough sources to enable me to determine the status of current information. Criteria available in the literature appear to me to fall into three groups which can be called 'constants', 'specific principles', and 'general principles'. The constants are items that can be standardized within a system or between systems and include such things as labeling and spacing displays and controls. Specific principles include items such as 'design so an operator's hand will not cover a critical display while operating a related control'. General principles in the literature fall into four areas and concern grouping of panel components according to the function they perform; the sequence in which they are used; the importance of their use; or the frequency of their use."

Most of the sources which Bill reviewed grouped "specific principles" and "general principles" together. Bill said, "I think that there is little dispute over application of specific principles; however, considerable conflict arises over application of general principles. For example, if in a panel dealing with tracking a satellite and sending it commands, the various tracking and commanding operations are intermixed, it is not clear whether the components on the panel should be arranged according to

[1] Abbreviation for Independent Development Project.

function or the sequence in which they are used. If new or better layout criteria are to be developed, it is in the area of resolving application of the general principles that the effort must be expended." The list of sources reviewed by Bill Williams is described in greater detail in Exhibit A-3.

Panel Design Test

Bill decided that a good way to gain some insight into the value of panel layout criteria might be to organize a panel design test which could be given to people with varying degrees of exposure to human factors problems and human factors literature. Subjects chosen for the test would range from college freshmen engineering students to professional designers. Human factors experts would then rate the panels by predicting the performance of each panel. The panel designs would be fabricated, installed in a console, and tested by twenty operators previously unfamiliar with similar equipment. Each operator's response time in performing various sequences of operations would be measured by electronic timers. This data would be used to determine the operator's learning rate and error frequency for the test. Bill felt that response time, learning rate, and error frequency were the three most important performance parameters of panel operation.

Tracking and Commanding Control Console

Bill chose to simulate a "tracking and commanding" console panel for the design test. The function of this panel was to control tracking of a space satellite by a ground station telemetry antenna, transmit commands to the satellite, and verify satellite execution of these commands.

Under standard operational procedure, the panel operator's first responsibility was to check indicator lights to determine whether all support equipment was ready, including the telemetry antenna, telemetry ground station tracking computer, and other electronic equipment. After the operator had determined that the system was ready, he reported to the test controller who told the operator which tracking mode to select and the position to select for the tracking antenna.

After the antenna began following the satellite, the operator reported the track status to the controller who provided command information to the operator. The operator then selected the command mode, verified that telemetry was being received by the satellite and the tracking was "go", and then entered and initiated the command with numerical switches. The sequence of operations necessary to perform these tasks and the interrelationship of console controls is described in greater detail in Exhibit A-4.

Console Environment

The console panel operations specified for the Human Factors criteria test by Bill Williams for a single panel were actually distributed over several consoles in a typical ground station control room operated by several people whose tasks were interrelated. A typical ground station had a central control room in which were located separate console for directing track and command operations. Electronic equipment connected to these consoles were located in adjacent equipment control rooms in rack-mounted units. Equipment operators read dials which monitored the track and command equipment performance.

A panel operator in the central control room was typically an Air Force officer with an engineering background and extensive training in the operation of the panel. The operator manned the panel only during a satellite pass, which typically required from 15 to 30 minutes. Bill Williams commented, "After the tracking and controlling operations were completed, the operator generally returns to other work." The operator often had to talk with other operators in the control room, primarily through earphone-microphone headsets. A typical central control room is described in greater detail in Exhibit A-5. A typical equipment control room is described in greater detail in Exhibit A-6.

When errors or malfunctions occurred in support equipment such as an electronic computer, the panel operator could correct the situation by switching to a back-up system. Bill Williams noted that there might be more than one back-up system required or none at all. In the latter case, it was necessary to repair the malfunctioning equipment before any control operations could continue. This was particularly true in the case of the telemetry antenna which was a large, parabolic dish located near the communicating ground station. A typical telemetry antenna of the type used for satellite communications is described in greater detail in Exhibit A-7.

Console Hardware

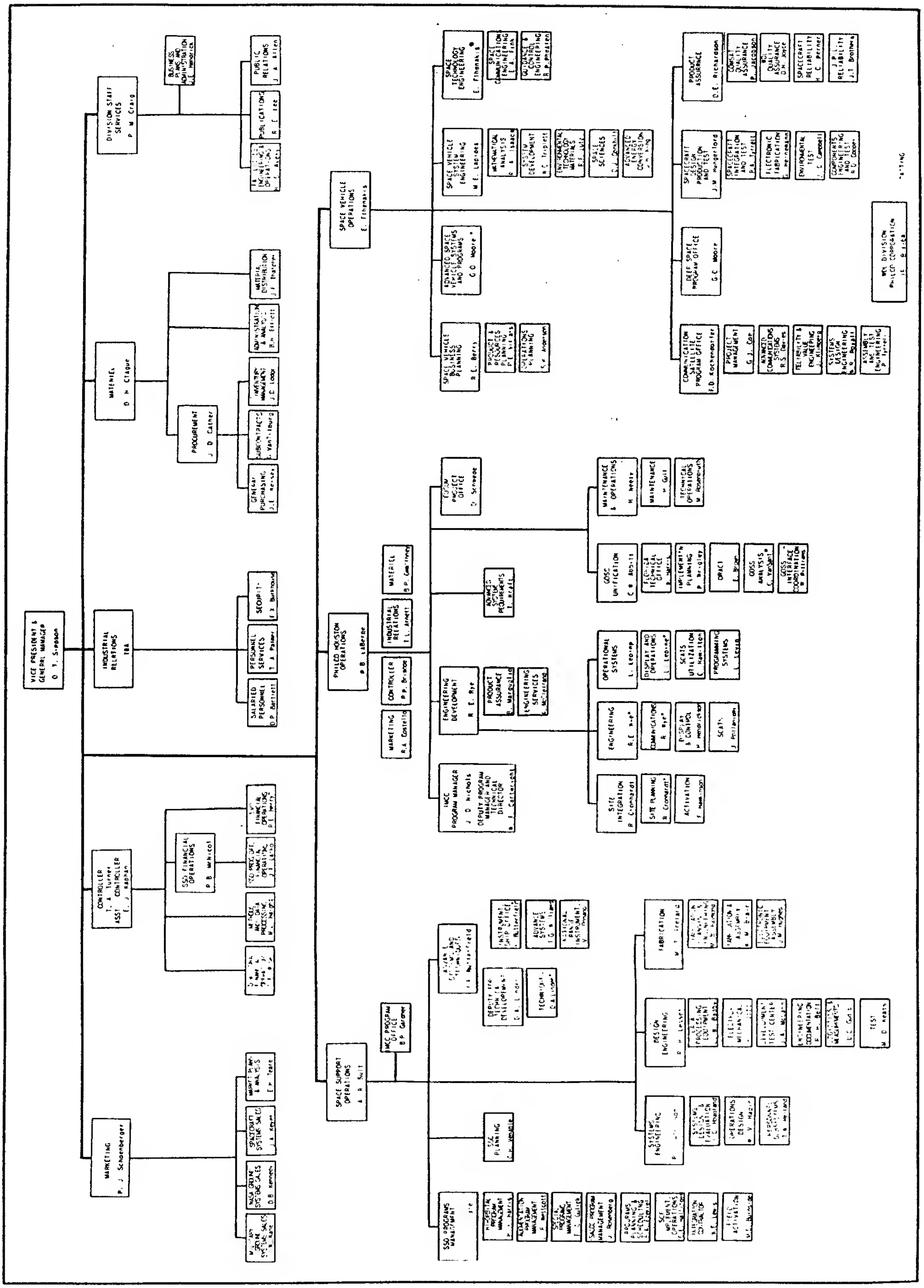
Each opertor of the Track and Command Control Console for Bill's test communicated with the Test Controller via earphone-microphone; however, the operator was not required to see any visual displays except his own panel. The test room was maintained at 72°F, and the lighting intensity was adjusted to 30 foot candles to allow the operators to see back-lighted displays and switches. The dimensions of the seating arrangement for the operator are described in Exhibit A-8.

The switches and controls specified for the test panel were standard items used by Philco in the construction of ground support equipment. These items are described in greater detail in Exhibit A-9 in the Hardware Function List. The number preceding each piece of hardware corresponds to the number located to the upper right of each symbol on the function diagrams. Although a given number may appear several times on the function diagram, only one such item can be used on the panel. A subscript "a" noted on the Function List represents a separate piece of

hardware. Pictures of the switches and controls are included in Exhibit A-10. The space physically required on the panel for each type of control is described in the Mounting Dimensions List in Exhibit A-11. Each designer was given an envelope containing cardboard cut-outs of the components. Bill provided a "Nomenclature Guide" for the components and panel in order to insure some degree of uniformity in the panel labeling. This guide is described in Exhibit A-12.

The space available for mounting components was 36 inches by 22 inches. Bill stated that it was not necessary to use all of the available space. He said, "A considerably larger panel might have a lower error frequency, but operator reaction time would be longer. The operator generally has approximately 15 to 30 minutes to complete the tracking and commanding operations, depending upon the orbit altitude of the satellite. I think that there is a strong correlation between the error frequency, reaction time, and learning rate, and that if panel layouts are significantly different, these performance parameters will indicate it. However, with the information we have provided about the function of the equipment, it may be possible for a person to come up with a good performing design with 'common sense'."

Exhibit A-1. WDL Organization Chart.



MIL-H-27894(USAF)

STANDARDS

MILITARY

MIL-STD-203	Cockpit Controls Location and Actuation of, for Fixed Wing Aircraft
MIL-STD-250	Cockpit Controls Location and Actuation of, for Helicopters
MIL-STD-411	Air Crew Station Signals
MIL-STD-803	Human Engineering Design Criteria for Aerospace System Ground Equipment

USAF SPECIFICATION BULLETIN

523	Space Environment Criteria for Aerospace Vehicles

PUBLICATIONS

AFSCM 80-1	Handbook of Instructions for Aircraft Designers (HIAD)
AFSCM 80-3	Handbook of Instructions for Aerospace Personnel Subsystem Designers (HIAPSD)
AFSCM 80-5	Handbook of Instructions for Ground Support Equipment Designers (HIGED)
AFSCM 80-6	Handbook of Instructions for Aircraft Ground Support Equipment Designers (HIAGSED)
AFSCM 80-8	Handbook of Instructions for Missile Designers (HIMD)
AFSCM 375-1	Configuration Management During the Acquisition Phase

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 GENERAL. The principles, procedures, and criteria of human engineering shall be applied in the acquisition of aerospace systems and equipment to ensure that adequate consideration is given to the capabilities and limitations of man as a component of the system. Within the parameters established by the system requirements, a human engineering effort shall be provided whose objectives shall be to increase and preserve the effectiveness of the human component during the operation, maintenance, and control of the system, and to reduce demands upon manpower resources, skills, training, and costs.

3.1.1 HUMAN ENGINEERING EFFORT. The human engineering effort shall include active participation in the three following major interrelated areas of system acquisition:

a. System analysis (as specified in MIL-D-9310, MIL-W-9411, MIL-D-9412, and MIL-M-26512, or as otherwise specified) to identify and define the system operation, maintenance, and control functions, and to allocate these functions to man, equipment, or man and equipment.

b. Selection, definition, and detail design of equipment, procedures, work-environments, and facilities associated with the system functions requiring human performance.

c. Acceptance testing and the system test and evaluation program to verify that the design of equipment, procedures, work-environments and facilities meet human performance requirements and are compatible with the over-all system requirements.

3.1.2 NON-DUPLICATION. The analyses required to accomplish the human engineering effort specified herein shall not duplicate analyses performed in accordance with other specifications or exhibits. Appropriate use shall be made of applicable function and task data derived from analyses performed in accordance with specifications MIL-D-9310, MIL-W-9411, MIL-D-9412, MIL-P-25996, MIL-D-26239, MIL-M-26512, MIL-D-27382, and MIL-R-27542.

Exhibit A-3. Literature Survey

LITERATURE SURVEY OF PRESENT CRITERIA IN USE

1. E. McCormick, Human Engineering, McGraw-Hill, 1957, p. 368.

2. Cornell Aeronautical Laboratory, "Pocket Data for Human Factor Engineering," Report No. UB-1227-U-3, 1962, p. 47.

3. C. Morgan, J. Cook, A. Chapanis, M. Lund, Human Engineering Guide to Equipment Design, McGraw-Hill, 1963, p. 298.

4. Human Factors Department, Philco, W.D.L., "Human Engineering Detail Design Criteria," Appendix B, 1963, sec. 3.5.

5. "Handbook of Instructions for Ground Support Equipment Designers," HIGED, AFSCM 80-5, May, 1955, sec. 7.4.

6. Wesley E. Woodson, "Human Engineering Design Standards for Spacecraft Controls and Displays," Preliminary Draft, General Dynamics/Astronautics, 1963.

7. "Layout of Work Places," Chapter V of the Joint Service Human Engineering Guide to Equipment Design, W.A.D.C. Technical Report 56-171, 1956.

8. "Design of Controls," Chapter VI of the Joint Services Human Engineering Guide to Equipment Design, W.A.D.C. Technical Report 56-172, 1956.

9. ASTIA Bibliographies from 1960 to Present.

Exhibit A-4. Panel Operational Procedure

The standard operational procedure for the test panel was as follows: the operator's first responsibility was to determine the operational status of his equipment. Status lights provided this information. At least one of the "Command Computers", "Telemetry Computers", "Tracking Computers", "Telemetry Ground Stations", "Antennas", "Command Processors", "Receivers", and "Transmitters" had to be operable or "go" before the tracking and commanding tasks were started. After the operator had determined that the system was ready, he reported to the test Controller who informed the operator of the track mode he was to use and the azimuth and elevation positions he was to select on the "Ax. Position Select" and "El. Position Select" controls respectively.

The "Semi-Auto Track" mode, "Auto Track" mode, and "Slave Track" mode were all independent and only one could be engaged at a time. In the Semi-Auto Track mode, the Az. and El. positions had to be selected prior to pressing the Start Track control. The error conditions that will inhibit acquiring the vehicle track are shown on the Tracking Function Diagram. For each error, the appropriate correction control and display is given. If the "Auto Track" or the "Slave Track" mode were used and "tracking" was not established after all possible corrective action had been taken, the operator had to use the "Semi-Auto" mode to complete the tracking operation.

After tracking was established, the "Semi-Auto/Auto Track Select" control and display had to be activated when either the "Semi-Auto" or "Auto" tracking modes was used. This control was not activated when the slave model was used.

At this time, the operator reported the track status to the Controller who provided command information to the operator. This information included the command mode, a list of commands in numerical form, and the sequence for sending the commands. Several command modes were often used during a sequence of commands. The operations necessary to send a command are diagrammed in the Commanding Function Diagram.

In the normal pattern of the command operation, the operator selected the command mode, verified that telemetry or "TLM" was being received and that the tracking was "go", and then entered and initiated the command. If all the support equipment were functioning, the receiving and executing of the command by the vehicle was verified. It was possible to send another command in the same or different mode immediately after execution.

Exhibit A-4 (cont.) Panel Operational Procedure

The Command Function Flow Diagram indicates the error conditions that can inhibit the command operation. In the "Computer A" or "Computer B" modes, the command operation was all automatic and was interrupted only by pressing the "Stop Command" control. This control inhibited the commanding operation and permitted the operator to correct error conditions. Error conditions that occurred had to be corrected before the commanding could be completed. Each error condition had an error correction control (except "Improper Command") which corrected the error and extinguished the error light. Before commanding could resume, the "Command Clear" control was pressed to clear the command sequence. When the "Command Clear" control did not clear the operation in the "Manual Command-Repetitive", "Computer A" or "Computer B" modes, the commanding was completed on the "Manual Command-Single" mode.

Exhibit A-4. Panel Operational Procedure,
Track Diagram.

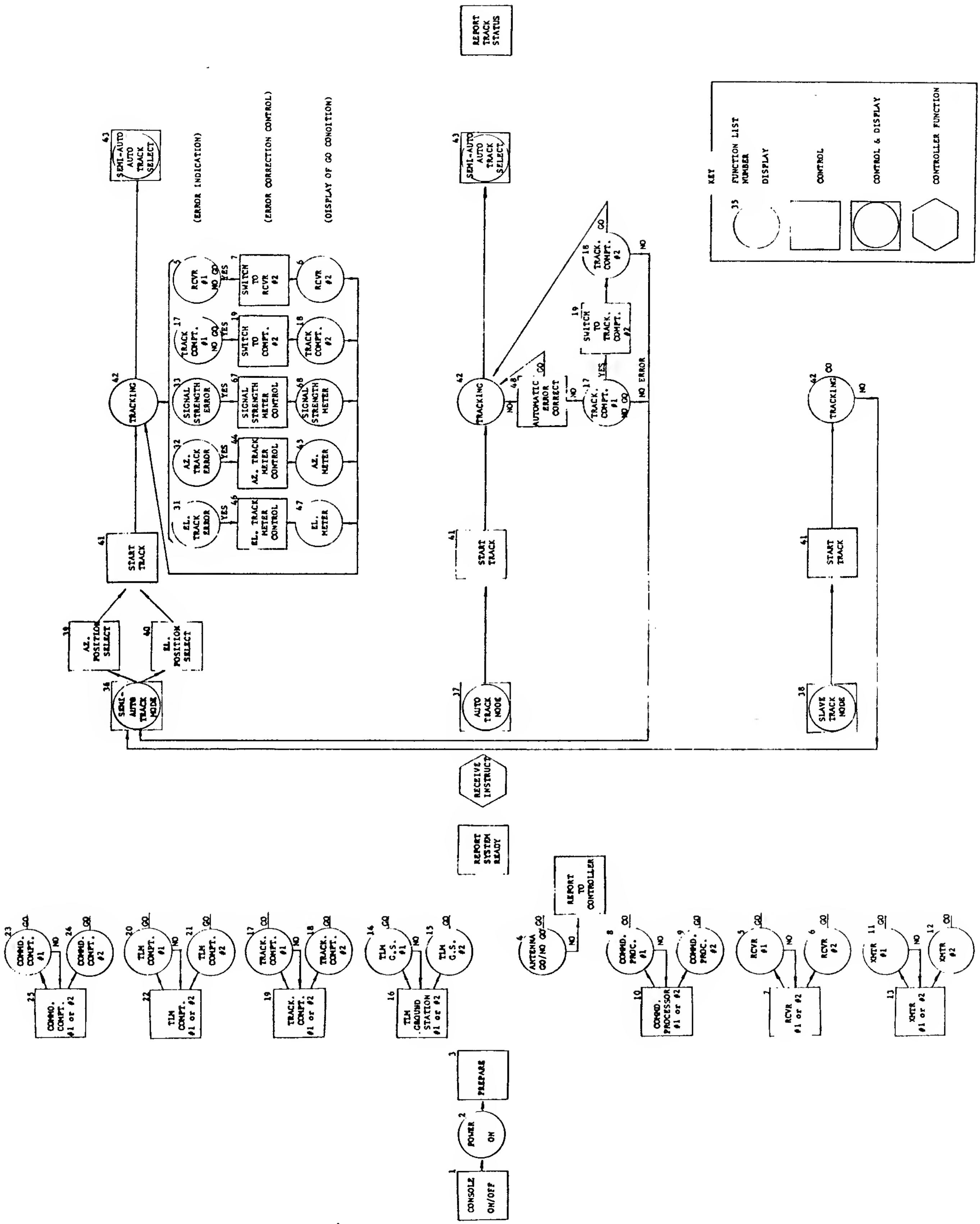


Exhibit A-4. Panel Operational Procedure,
Command Diagram.

ECL 25
ME 112b-2

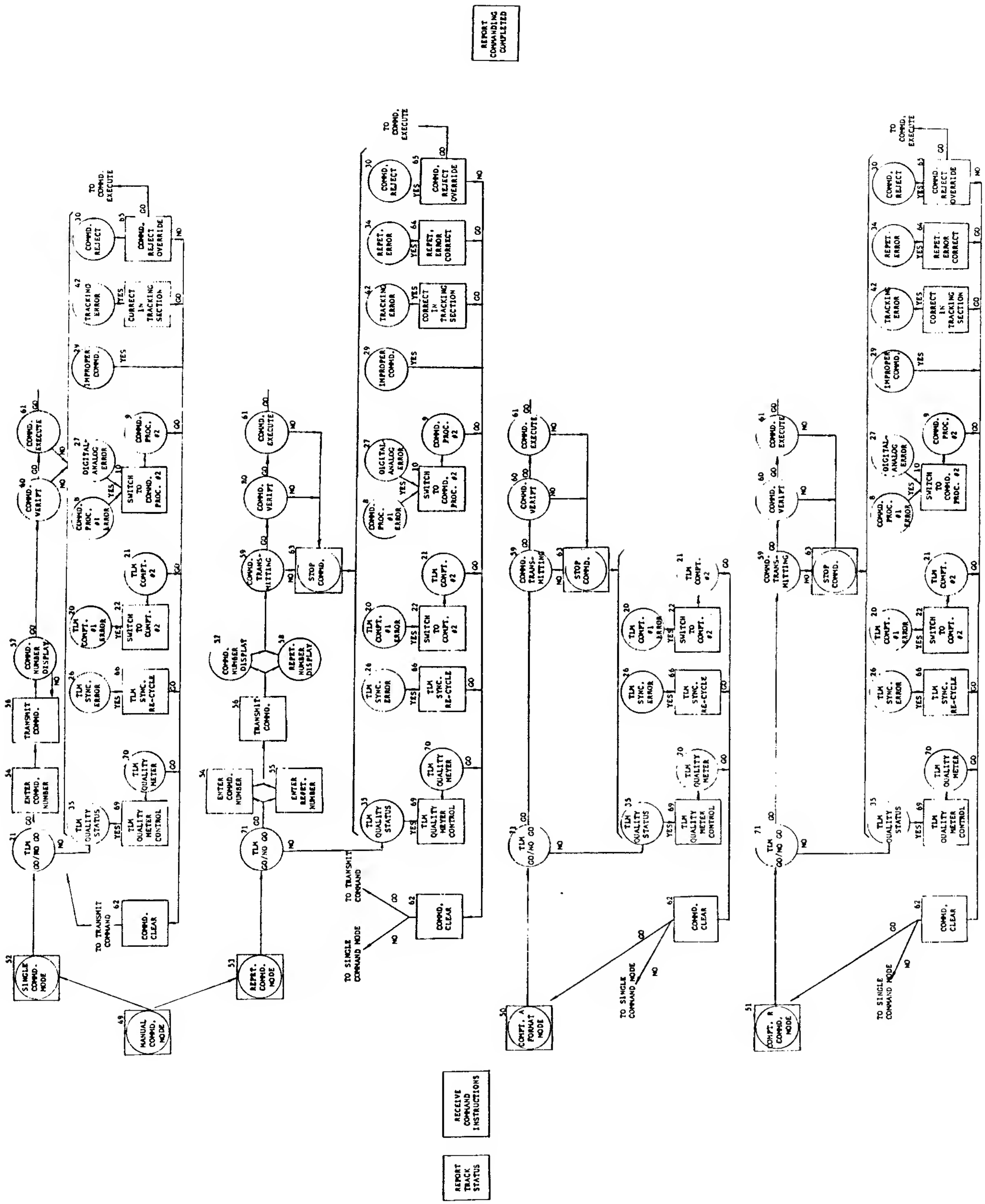


Exhibit A-5 Ground Station Equipment Control Room.

Exhibit A-6. Telemetry Antenna.

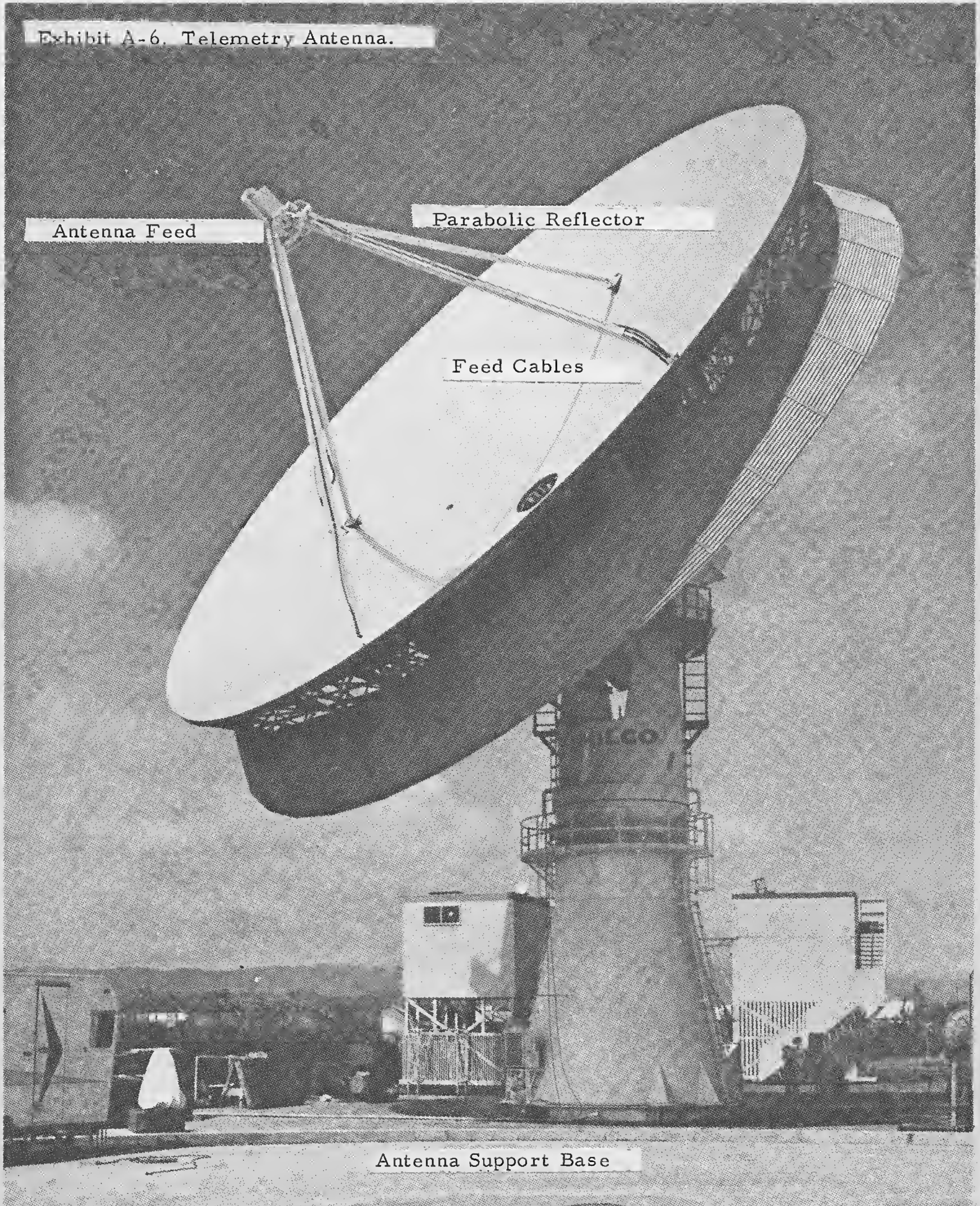
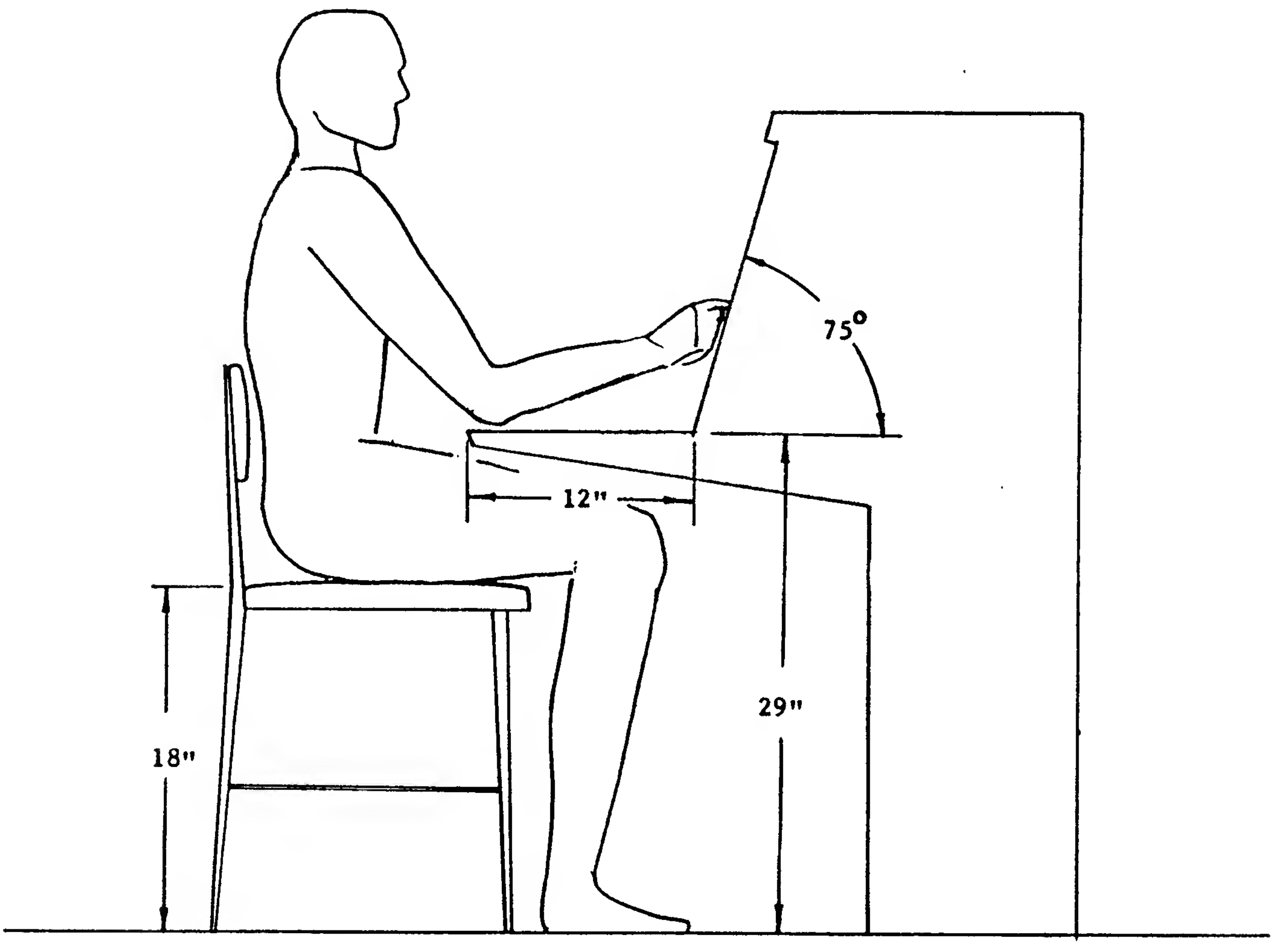


Exhibit A-7. Console Dimensions.

Note: The following dimensions were taken from the <u>Human Engineering Guide to Equipment Design</u>, McGraw-Hill, 1963.



Courtesy of Philco Corporation

Exhibit A-8. Hardware Function List

	NOMENCLATURE	HARDWARE	FUNCTION	NOTES
1.	Console On/Off	Toggle 2-Position	Power to Console	Dual control at controller's position-can operate from either position.
2.		Dialco Pilot Lamp	Indicates power on at console	Above toggle-activates light.
3.	Prepare	Toggle 2-Position	Lights status of equipment. Either a go-no go; primary or backup must light.	With light all indicators in either go-no go.
4.	Antenna - Go	Series #80 - Green	Status of antenna, red - no go, green - operating.	If no go, operator must verbally inform controller-controller will correct.
4a.	Antenna - No Go	Series #80 - Red		
5.	Rcvr. #1 - Go	Series #80 - Green	Status of Rcvr #1	Operator - corrects no-go condition by switching (No. 7) to Rcvr #2 (No. 6).
5a.	Rcvr. #1 - No Go	Series #80 - Red	Red - No Go Green - operating	
6.	Rcvr. #2	Series #80 - Green	Status - green - operating, Yellow - ready to operate; Is backup to Rcvr. #1.	Is used when Rcvr #1 goes to red-switch (No. 7) makes change. Yellow-goes out-green-on.
6a.	Rcvr. #2	Series #80 - yellow		
7.		Toggle 2-Position	To switch between Rcvr #1 & Rcvr. #2	
8.	Commd. Proc. #1 - Go	Series #80 - Green	Status of Processor - Green - Operating go. Red-no go.	Operator corrects no go (red) by switching (No. 10) to Command Processor #2 (No. 9).
8a.	Commd. Proc. #1 - No Go	Series #80 - Red		
9.	Commd. Proc. #2 - Go	Series #80 - Green	Like 6 above	Like 6 above. Backup for Commd. Proc. #1 (No.8).
10.		Toggle 2-Position	Switch between No. 8 & No. 9	
11.	XMTR #1 - Go	Series #80 - green	Status - like 4 above	correct no go by switching (No. 13) to XMTR #2 (No.12).
11a.	XMTR #1 - No Go	Series #80 - Red	Red-no go, green-go	

Exhibit A-8 (cont.) Hardware Function List

	NOMENCLATURE	HARDWARE	FUNCTION	NOTES
12. 12a.	XMTR #2 - Go XMTR #2 - Ready	Series #80 - green Series #80 - yellow	Like 6 above - backup for XMTR Yellow-marginal; green-operating	Like 6 above - backup for XMTR #1 (No. 11)
13.		Toggle 2-position	Switch between Nos. 11 & 12.	
14.	TLM G.S. #1 - Go TLM G.S. #1 - No Go	Series #80 - Green Series #80 - Red	Status - Like 4 above Red - No Go, green-operating	Correct no go by switching (No. 16) to TLM G.S. #2.
15.	TLM G.S. #2 - Go TLM G.S. #2 - Ready	Series #80 - Green Series #80 - Yellow	Status - Like 6 above; Yellow-Standby, green-operating.	Used when TLM G.S. #1 goes to red condition.
16.		Toggle 2-position	Switch between 14 & 15	
17. 17a.	Track Comp. #1-Go Track Comp. #1 - No Go	Series #80 - Green Series #80 - Red	Status - Like 4 above Red-No Go, green-operating	Correct No go by switching (No. 19) to Track Comp. #2 to (No. 18).
18. 18a.	Track Comp. #2-Go Track Comp. #2-Ready	Series #80 - Green Series #80 - Yellow	Status Yellow - Standby Green - Operating	Used when TLM G.S. #1 goes to red condition.
19.		Toggle 2-position	Switch between Nos. 17 & 18	
20. 20a.	TLM Comp. #1 - Go TLM Comp. #1-No Go	Series #80 - Green Series #80 - Red	Status - red - no go - green operating.	Like 17 above.
21. 21a.	TLM Comp. #2-Go TLM Comp. #2-Ready	Series #80 - Green Series #80 - Yellow	Status - Yellow - Standby Green-go	Backup - like 18 above.
22.		Toggle 2-position	Switch between 20 & 21.	
23. 23a.	Commd. Comp. #1 - Go Commd. Comp. #1 - No Go	Series #80 - Green Series #80 - Red	Status - red - no go Green - operating	Like 17 above.
24. 24a.	Commd. Comp.#2-Go Commd. Comp.#2-Ready.	Series #80 - Green Series #80 - Yellow	Status - Yellow-standby Green-operating	Backup like 18 above.
25.		Toggle 2-position	Switch between Nos. 23 & 24.	
26.	TLM Sync Error	Series #80- Red when on	Error indication-when off, TLM Sync OK.	Condition is corrected by activating Re-cycle TLM Switch (No. 66) then clear (No. 62).

Exhibit A-8 (cont.) Hardware Function List

NOMENCLATURE	HARDWARE	FUNCTION	NOTES
27. Digital/Analog Error	Series #80-Red when on	When red error condition When no light-OK.	Condition is corrected by activating Commd. Processor backup (No. 9) and Clear Command (No. 62)
28. Eliminated			
29. Improper Command	Series #80-Red when on	Like 27 above	Condition is corrected by activating Command Clear (No. 62).
30. Command Reject	Series #80 - Red when on	Like 27 above	Condition is corrected by activating Command Reject Override (No. 65) or if that fails, Command Clear (No. 62).
31. El Track - Error 31a. El Track - Marginal	Series #80's - Red Series 80 - Yellow	Error and marginal status indication, red-loss of track, yellow-track marginal.	Activation of red causes Tracking Indicator (No. 42) to go out. Yellow marginal condition - no loss of track-correction is to rotate meter contol (No. 40). When meter correct - indicators change back to go state.
32. AZ Track - Error 32a. AZ Track - Marginal	Series #80 - Red Series #80 - Yellow	Like 31 above	Like 31 above. Causes Tracking (No. 42) to go out. Correction Control (No. 39).
33. Signal Strength-Error 33a. Signal Strength-Marginal	Series #80 - Red Series #80 - Yellow	Like 32 above	Like 32 above. Correction control (No. 67).
34. Repeat Error	Series #80 - Red	Indicate error in the repetitive mode after Command transmitted. When light off-no error	Error can come on only after Command Transmitting (No. 59) goes out. Stop Command (No. 63) must be activated, then error corrected by activating Repetitive Correct (No. 64) switch. Then clear (No. 62).
35. TLM Quality - Go 35a. TLM Quality-Marginal	Series #80 - Red or Yellow.	Similar to 31, 32, 33- Red-loss of adequate TLM- Yellow- TLM is marginal but OK	Condition goes on when TLM Receive (No. 71) goes out. Yellow condition no loss of quality but need correction. To correct-rotate Meter Contol (No. 69).

Exhibit A-8 (Cont.) Hardware Function List

NOMENCLATURE	HARDWARE	FUNCTION	NOTES
36. Semi Auto-Track	Series #10 - White	Puts track in semi-auto mode; disengages other modes No. 37 & No. 38.	Controller informs operator of mode to be used. Applies to No. 36, 37 or 38.
37. Automatic Track	Series #10 - White	Like 36 above. Disengages No. 36 & 38.	See No. 36 above.
38. Slave Track	Series #10 - White	Like 36 above. Disengages Nos. 36 and 37.	See No. 36 above.
39. AZ Position	4-Position Rotary Switch	To set Radar AZ Axis-prior to track-positions, Off 0° - 160° - 220°.	To set Radar - No further action needed. Setting is validated by fact that antenna is tracking - For use in "Semi-Auto Track" (No. 36) only.
40. El Position	4-Position Rotary Switch.	To set Radar EL Axis prior to track - Off 0°-45°-90°	Like 39 above.
41. Start Track	Micro-Switch	Begins track function for all Track Modes (Nos. 36, 37,38).	If System OK-Tracking indicator (No. 42) will light green.
42. Tracking	Series #80 - Green	Indicates that antenna is tracking.	Indicator goes out if any related error indication comes on.
43. <u>Semi-Auto</u> Auto	Series #10 - White	In "Semi-Auto" mode - this control is manual means (press) to lock on antenna. In "Auto-Track" comes on automatically.	After Tracking indicator (No. 42) on this control or display is employed.
44. AZ Track	Rotary (continuous)	Controls meter No. 45 setting.	Used when meter goes off green position.
45. AZ Track	Meter	Shows AZ track OK - green area; marginal-yellow; out-red.	Controlled by (No. 44)-(No. 32) AZ track indicator will change with meter.
46. EL Track Control	Rotary (Continuous)	Controls meter No. 46 Setting.	Like 44 above.
47. EL Track	Meter	Like 45 above.	Like 45 above.

Exhibit A-8 (cont.) Hardware Function List

NOMENCLATURE	HARDWARE	FUNCTION	NOTES
48. Auto Track Correct	Micro-Switch	In automatic Track mode (No. 37) if "Tracking" Indicator (No. 42) goes out, this control may correct and turn light back on.	If this does not correct-problem error may be in Command Processor #1 (No. 8).
49. Manual Command	Series #10 - White	Select Mannual Command Mode disengage (No. 49 & 51).	
50. Computer A Command	Series #10 - White	Select Computer A format mode disengage (No. 49 & 51).	
51. Computer B Command	Series #10 - White	Select Computer B format mode disengages (No. 49 & 51).	
52. Single Command	Series #10 - White	With "Manual" Mode (No. 49) Commands can be sent out one at a time.	Used only with manual mode.
53. Repetitive Command	Series #10 - Whie	With "Manual" Mode (No. 49) to send out a command a number of times (repeat). Disengages No. 52.	Used only with manual mode permits use of Repetitive Digit Switch.
54. Command Enter	Digiswitch - 2 digit	To enter command number to be transmitted either single or repetitive.	Number selected prior to transmit.
55. Repetitive Enter	Digiswitch - 1 digit	Enter by number - it is the times a command entered in (no. 54) is to be repeated.	Use with repetitive mode (No. 53) only.
56. Transmit Command	Micro-switch	To transmit command	Activated after commands are entered in manual mode - not used in Computer A or B modes.
57.	IEE Series 120 2 digit - display	Displays "Command Entered" (No. 52) after "Transmit" Switch (No. 56) has been activated.	If number doesn't appear "Transmit Command" activated again.
58.	IEE Series 120 1 digit display	Display "Repetitive Enter" (No. 55) after "Transmit" Switch (No. 56).	If number doesn't appear-activate "Transmit Command" again.

Exhibit A-8 (cont.) Hardware Function List

NOMENCLATURE	HARDWARE	FUNCTION	NOTES
59. Commd. XMTR Go 59a. Commd. XMTR - No Go	Series #80 - Green Series #80 - Red	Indicates command tranmitting (green); when red-command not transmitting.	Used only in Repetivie Manual & Computer A & B Modes - Not manual single command - Stop command (No. 63) will turn off this function.
60. Commd. Verified	Series #80 - White	Indicates single or all multiple commands received by vehicle.	If no indication - some error condition exists. Possible error conditions are Nos. 20, 26, 30, 29, 71, 42, 34, 11, 27, & 35.
61. Command Executed	Series #80 - White	Indicates single or all multiple commands executed by vehicle.	If no indication-some error condition exists. Possible error conditions are shown with (No.60).
62. Command Clear	Micro-Switch	Clears command sequence after errors detected and corrected. (No. 60 & 61 above).	This control must be activated before commanding can begin after error detection and correction.
63. STOP Command	Series #10 - Red	Activation stops command	Used in Computer A (No. 50) & B (No. 51) and Repetitive (No.53) modes - When "Command Transmit" (No. 59) goes out and error conditions light. Must be activated before errors corrected. Will turn off command transmitter (No. 59).
64. Repetitive Correct	Micro-Switch	When "Repetitive" error indicated (No. 34). Activating this control will correct error used in "Manual" "Repetitive" modes only.	When activated "Repetitive" error goes off-must "Command Clear" (No. 62) and enter commands again.
65. Command Reject Override	Micro-Switch	When "Command-Reject" error (No. 30) goes on-this control may correct.	If does not correct, must activate "Command Clear" (No. 62).
66. Re-Cycle TLM	Micro-Switch	When TLM SYNC error (No. 26) goes on. This control will correct.	After correct--must activate "Command Clear" (No. 62) and begin command enter.

Exhibit A-8 (cont.) Hardware Function List

NOMENCLATURE	HARDWARE	FUNCTION	NOTES
67. Signal Strength	Rotary (Continuous)	To control Signal Strength Meter (No. 68).	Control effects status of Signal Strength indicator (No. 33). Tracking indicator (No. 42).
68.	Meter	Indicates Signal Strength status - green area OK	Only red condition causes "Tracking" (No. 42) to go out.
69. TLM Quality	Rotary (Continuous)	To control TLM quality meter (No. 72).	Control effects status of "TLM Quality" indicator (No. 35) "Tracking" indicator (No. 42).
70.	Meter	Indicates TLM quality status	Green area - OK - Yellow - marginal and red out - Red "Tracking" 42 - out.
71. TLM Go 71a. TLM No Go	Series #80 - Green Series #80 - Red	When TLM being received ON green on - when light off an error condition exists.	TLM error No. 35 indicates no go on marginal situation - corrected by control (No. 69) - Display Meter (No. 70).

Exhibit A-9 Hardware Mounting Dimensions

FRONT MOUNTING SIZE DIMENSIONS OF CONTROLS & DISPLAYS

1.	Series #10 Illuminated Pushbuttons	1-1/4" by 1"
2.	Series #80 Illuminated Pushbuttons	1" by 3/4"
3.	Meters	3-1/8" by 1-3/4"
4.	Digiswitch (2 digit)	1-3/8" by 1-3/8"
	Digiswitch (1 digit)	7/8" by 1-3/8"
5.	Rotary Knobs (pointed)	7/8" by 1-1/4"
6.	Rotary Knobs (skirted)	1" diameter
7.	Toggle Switch	3/4" diameter - See sample
8.	IEE Readout Display (2 digit)	2" by 13/16"
	IEE Readout Display (1 digit)	1" by 13/16"
9.	Micro-Switch	7/8" diameter
10.	Dialco Indicator	1/2" diameter

CONTROL & DISPLAY BACK PANEL SIZE DIMENSIONS

The following controls and displays require additional mounting space behind the panel surface. The controls and displays not mentioned do not require additional back panel mounting space.

1.	Meters	2-1/2" by 3-1/8"	-	Space Required
2.	Digiswitch (2 number)	2" by 2"	-	" "
3.	Digiswitch (1 number)	1-1/2" by 2"	-	" "
4.	Rotary Knobs	1-1/2" by 1-1/4"	-	" "
5.	Toggle Switch	1" by 1"	-	" "
6.	IEE Readout (2 number)	3-1/4" by 1-1/4"	-	" "
7.	IEE Readout (1 number)	2-1/4" by 1-1/4"	-	" "
8.	Dialco Indicator	5/8" diameter	-	" "

The front panel design should reflect the above space requirements.

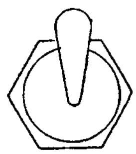
Exhibit A-10. Labeling and Nomenclature Guide

1. All the series #80 and #10 indicators will have the function name stamped on the lens. The nomenclature will be the same as that given on the Function Lists.

2. The following nomenclature and arrangements will be required. The number given with each control corresponds with the Function List number.

#1 Console Power

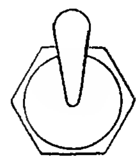
On



Off

#2 Prepare

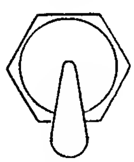
On



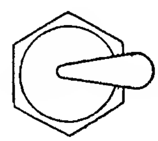
Off

#7, 10, 13, 16 - 19, 22, and 25 - 3 options

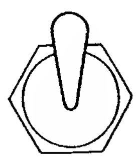
Example: XMTR #1

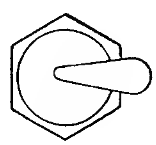


XMTR #2

or XMTR #2  XMTR #1

or





-without nomenclature but used in conjunction with the appropriate display.

#39 & 40 EL Position or AZ Position

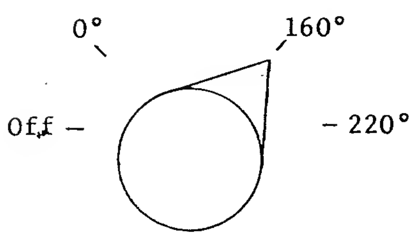
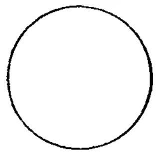


Exhibit A-10 (cont.) Labeling and Nomenclature Guide

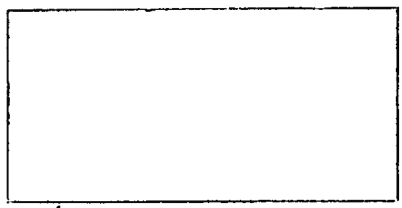
#41, 48, 56, 62
64, 65, 66

Example: Start Track



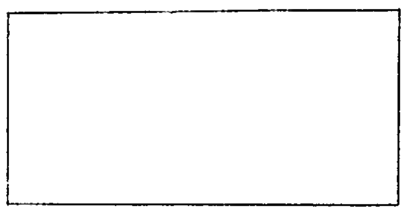
#44, 45, 46, 47
67, 68

Example: AZ Track - Title on Top



#54, 55

Example Command Enter - Title on Top



3. The following may be incorporated:

   a. Grouping and sub-grouping of controls and displays.
      Group and sub-group headings may be used. These grouping can be line boxed and labeled with group titles. All headings will appear at the top of the grouping.

4. Letter size and line width.

   a. Labeling on pushbuttons will be 1/8 inch.
   b. Major headings will be 3/16 inches.
      Minor headings will be 5/16 inches.
   c. Two line widths can be used.
      Narrow will be 20/1000 inch.
      Wide will be 60/1000 inch.

<u>NOTE:</u> These differences do not have to be drawn. Each can be labeled.

PHILCO CORPORATION (C)

Panel Evaluation and Testing

In January, 1965, Bill Williams was faced with the decision of interpreting results of testing performed on six tracking and commanding console panels. Bill said, "There were no significant performance differences among the six panels tested. This suggests that panel layout criteria were applied equally effectively by all panel designers and that prior design experience was not a significant factor in determining the effectiveness of various panel designs."

Bill noted that he had felt earlier in the project that the testing would evidence no difference in the panels. He said, "It makes it difficult to report this in the sense that the results go deeply against tradition. One also doesn't find negative results reported in the literature. In the sense that there is a need for determining the value of detailed layout criteria, however, the results of the testing may have a more positive character."

Prepared in the Design Division of the Mechanical Engineering Department by J. Kendall Williams under the direction of Robert H. McKim with financial assistance from the National Science Foundation. The assistance of Mr. William Williams is gratefully acknowledged.

Submitted Panel Designs

Nine Tracking and Commanding Console panels were individually designed by nine subjects with varying degrees of design experience and submitted to Bill Williams for testing. The designers included three freshman and two graduate Stanford mechanical engineering students, two Philco draftsmen, and two Philco Human Factors Engineers. Bill Williams said, "The purpose of selecting a group of designers with widely differing experience in traditional human factors design methods was to determine whether or not such exposure could affect the panel design and affect the operator's ability to perform. With this test I hope to gain some insight on the need for more detailed panel layout criteria." Of the nine panels designed, six were selected to be made and used by test operators. These six panels are shown in Exhbit C-1. The category of designer and time required for completion of the layout are noted in Exhibit C-1, page 2.

Bill noted that there were several major similarities in the layout of the panels. For the status indicators, there were 8 pieces of equipment represented. On all panels tests, the indicators were functionally grouped with some variability in the location of the group on different panels. For instance, the status indicators were grouped in a horizontal row at the top of panels 4 and 5, the center of panel 1, and the bottom of 6, in a vertical row in the center of panel 2, and in two vertical rows in the upper left quadrant of panel 3. The individual indicators within each functional group were placed in different sequences on various panels.

Bill noted that on all panels the pattern used for tracking controls was also used on the command controls. On panel 1, the tracking and commanding controls were arranged in sequence in a horizontal pattern with guidelines leading from one switch to the next. On panel 2, the control layout was a mixture of vertical and horizontal groups. On all other panels, the controls were sequentially grouped without guidelines.

Bill Williams noted that all the designers made some attempt to co-locate error condition indicators and the switches used to correct errors. Bill said, "Other than this co-location, the location of controls and displays according to the importance of their use was not a problem since the designers were told that all the hardware was of equal importance."

Panel Rating

Prior to fabrication of the panels, the designs were compared two at a time by three Philco WDL human factors personnel. The nine submitted panel drawings were ranked according to the frequency with which each layout was chosen as superior by each of three judges. Bill noted that there was little agreement among the judges as to the order of superiority of the panel layouts. He said, "The judges were naturally curious how the others had rated the panels. When one of them discovered a disagreement on a particular panel, he would antagonize the others, and very heated debates resulted."

To get around the problem of lack of consensus among the judges, Bill decided to choose at least one panel designed by a freshman, a graduate student, and a WDL engineer. Since only six panels could be tested due to time limitations, three additional panels were chosen for testing. Bill said, "The last three panels chosen were selected because they looked significantly different. In this way, we hoped to get a significant spread in performance. It seemed logical that designs with different appearance might have different performance characteristics." Panels Number 1, 2, and 5 were chosen first.

Experimental Procedure

After six panel designs were selected for testing and fabricated from 3/16 inch aluminum plate, 30 male college undergraduates were chosen for test subjects. The subjects had no prior experience in the operation of complex control equipment. The age of the subjects ranged from 17 to 64, while the mean age was 21.2 years.

The experimental procedure for each subject consisted of pre-test training, testing and de-briefing, all of which occurred in a single day. When three subjects were tested in a single day, they received pre-test training as a group. One of the three was tested immediately after the pre-test training and the other two returned separately later in the day. These subjects were given "refresher" training immediately prior to testing.

Pre-Test Training

Prior to testing, the subjects were given 50 minutes of instruction in the tasks they were to perform. The instructions were given by one experimenter who reviewed his notes prior to each briefing.

Ten minutes of the training was devoted to a description of the general nature of actual satellite tracking and commanding operations. The subjects were informed of the functions of the tracking controller, commanding controller, and ground station controller.

For an additonal 30 minutes, the experimenter explained the operation of the simulated system by means of a flow diagram. They were shown the test panel and the test controller's panel. The sequences of tasks, events, errors, and corrective actions which would occur during testing were explained. The importance of speed and accuracy were emphasized. The testing room environment is described in greater detail in Exhibit C-2.

After training, all subject's questions were answered. Bill said, "The instructions were complete in the sense that if the subjects fully understood them and remembered them, they could perform without errors at the test panel. We made no attempt to insure this degree of learning, however."

For the last ten minutes of training, the operation of the panel was demonstrated to all subjects to be tested on that panel. The sequences of actions required in the tests were performed by the experimenter who related them to the previous instructions. The subjects were not given an opportunity to operate the panel prior to actual testing.

Test Procedure

Each panel was tested on five subjects. All the subjects were tested in a fixed series of operational sequences which corresponded to the events which might occur at a tracking station in support of a single satellite operation. The subjects were told by the controller which tracking mode to select initially and were given lists of commands which they were to transmit in specific command modes. Each subject was first given an initial training trial during which no errors were injected by the test controller. Each subject was to perform a list of 15 operations without subject error. In the next trial, 7 errors were injected by the experimenter at fixed points in the sequence. In order to complete this sequence, each subject had to initiate the necessary corrective action. In six succeeding trails, 14 errors were introduced during each trial. The order and timing of error injection was varied from trial to trial. A list of the 15 operations appears in Exhibit C-2. The type of errors injected by the experimenter appears in Exhibit C-4. Data recorded during the tests included the age of the test subject, time required to complete each operational sequence, errors made, and the verbal cues given.

Two types of verbal cues were given. The first type consisted of complete instructions to the subject when he failed to correct an error within one minute. The second type consisted of hints given after the subject twice repeated an incorrect action, or twice failed to take a required action.

Performance Time

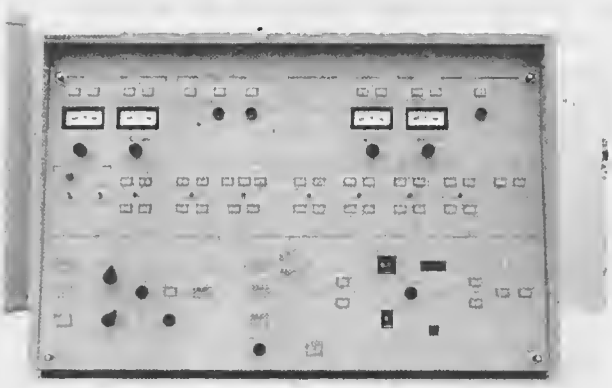
A statistical analysis of the test data was performed on the scores of individual subjects on each test trial to determine whether there were significant differences in performance time between subjects tested on different panels. Bill said, "The analysis of the data indicated that the mean performance time for the six panels tested was not significantly different between panels." The performance time data for the test series is included in Exhibit C-5.

Proposal Recommendations

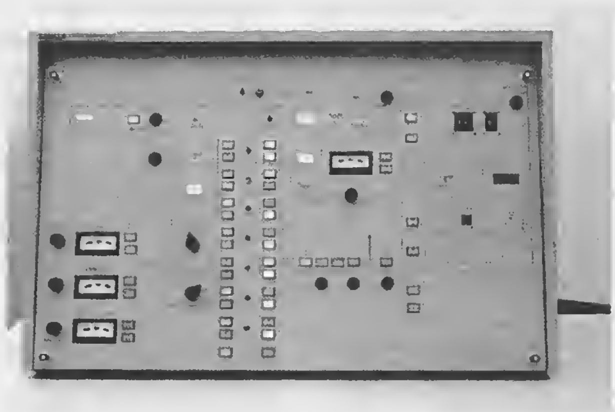
In organizing a proposal for further research into the value of detailed criteria, Bill Williams made several recommendations. He said, "The tests were performed under low stress conditions. Significant differences between panels might have been obtained if more error conditions had been introduced during the tests, or if the subject had less time to perform the operations. I think high stress conditions should be imposed to insure detection of differences in performance effectiveness. Low stress conditions should then be employed to determine the range of influence of this stress variable."

Bill also suggested that a future study include testing on a console consisting of small panels which could be individually arranged. He said, "In our tests, the value of the various arrangements within a panel tended to offset each other so that pooled performance measures did not reflect the effectiveness of individual arrangements. If the layout of the panel could be controlled with a panel constructed to permit systematic variation of layout characteristics of selected panel elements, differences in performance measures could then be attributed to the differences in the various arrangements of panel elements.

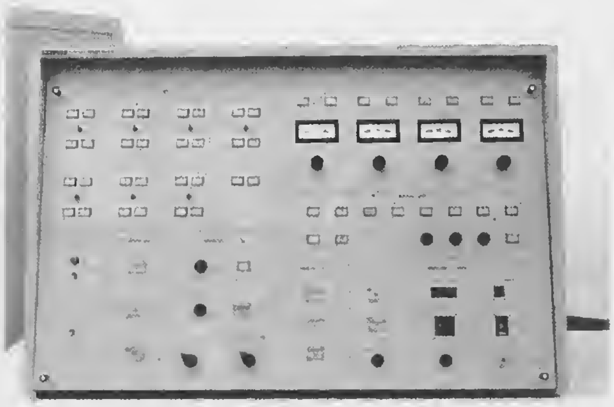
Exhibit C-1. Fabricated Test Panels.



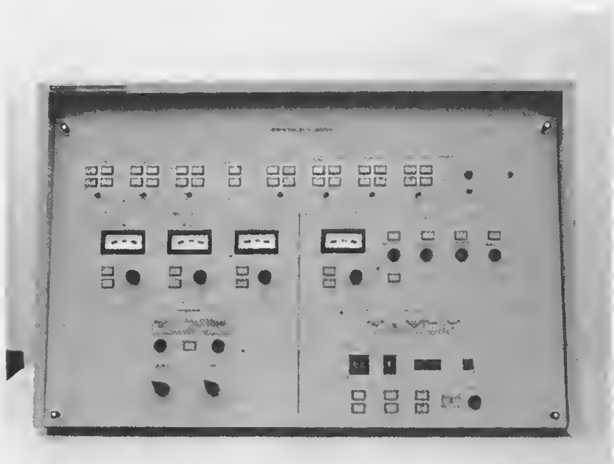
Panel #1



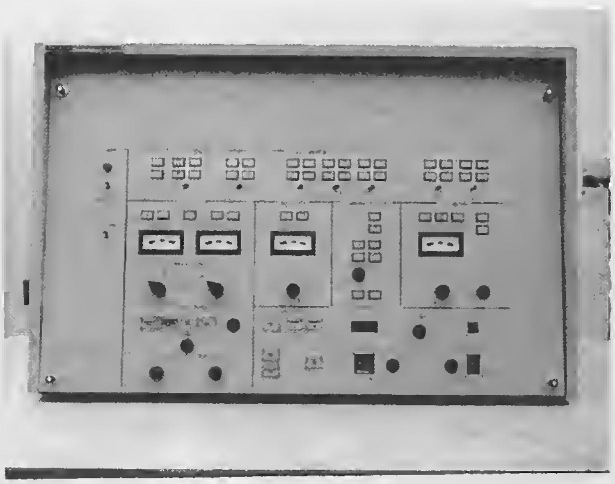
Panel #2



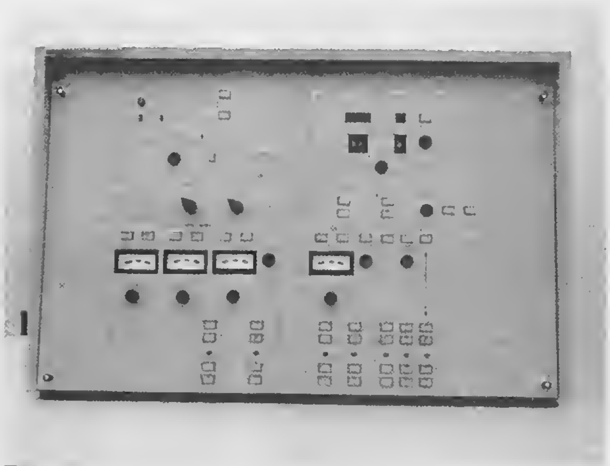
Panel #3



Panel #4



Panel #5



Panel #6

Exhibit C-1. Fabricated Test Panels.

PANEL NO.	DESIGNER	LAYOUT TIME (Hours)
1.	Graduate Student	18.0
2.	Freshman Student	13.5
3.	Philco Human Factors Engineer	20.0
4.	Philco Draftsman	26.0
5.	Philco Human Factors Engineer	26.0
6.	Freshman Student	17.0

Exhibit C-2. Panel Testing Environment.

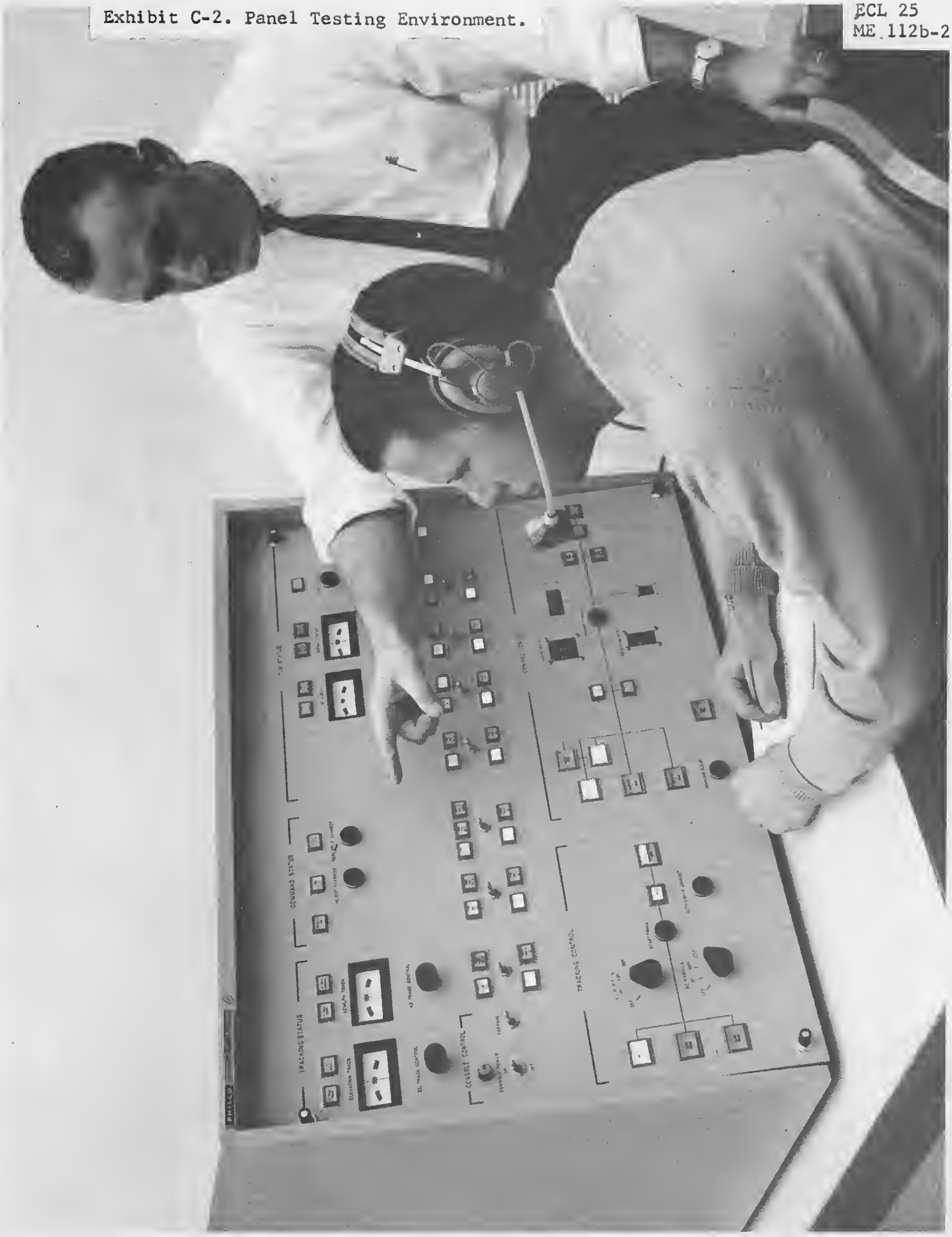


Exhibit C-2. Panel Testing Environment.

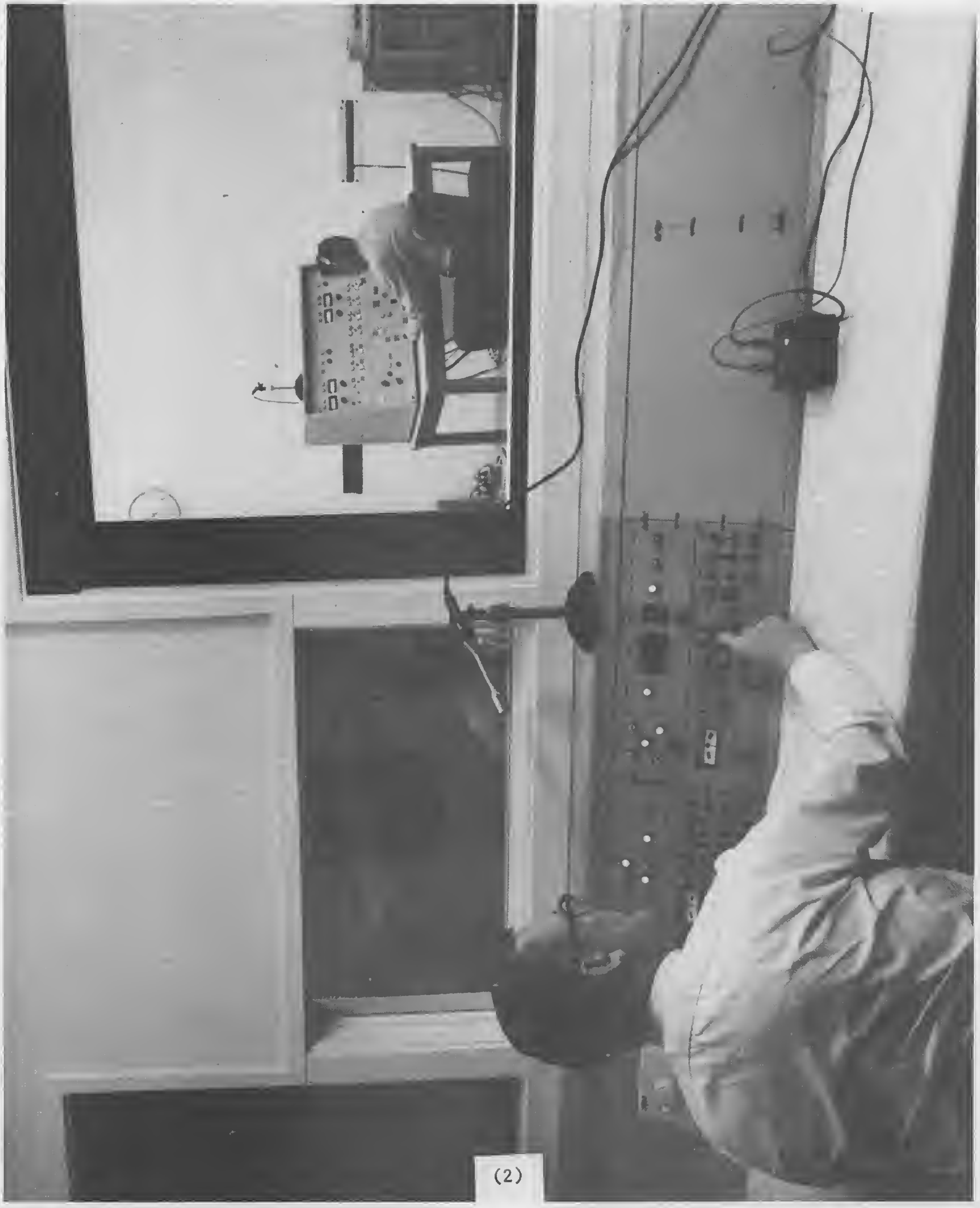


Exhibit C-3. Test Data

TABLE 4-2

MEAN TIME TO COMPLETE EACH TRIAL

Trial	Operational Sequence	Panel 1	2	3	4	5	6
T*	5a	9.94	11.21	9.47	9.54	9.45	10.42
1	1a	15.95	18.57	14.74	15.21	16.04	16.63
2	2a	13.65	15.32	13.00	12.20	12.90	13.06
3	1b	10.74	13.28	10.17	10.49	11.50	10.46
4	2b	10.20	11.47	10.33	9.92	9.76	9.97
5	1a	8.92	9.70	9.50	9.21	8.93	9.08
6	2a	9.17	10.12	9.38	8.62	8.57	8.15
7	1b	8.33	9.36	8.46	7.94	7.89	7.88
Mean	of Test Trials 1-7:	10.99	12.55	10.80	10.51	10.80	10.75

*Training trial

NOTE: Means (in minutes) are based on scores of five subjects tested on each panel.